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ABSTRACT

This paper reviews and analyzes research in science education which focused on science concepts and science concept learning. Studies reviewed are grouped into eight categories: (1) cognitive development, (2) factors influencing concept formation, (3) level of concept attainment, (4) methodological effects, (5) methodological comparisons, (6) curricular content, (7) instrument development, and (8) reviews and models. One hundred sixty-three studies are identified in the bibliography although not all of these studies are discussed in the review. (PEB)

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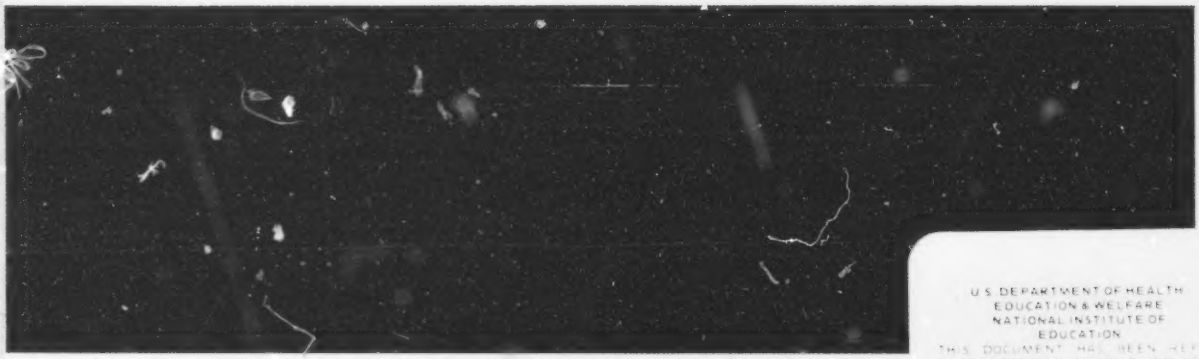

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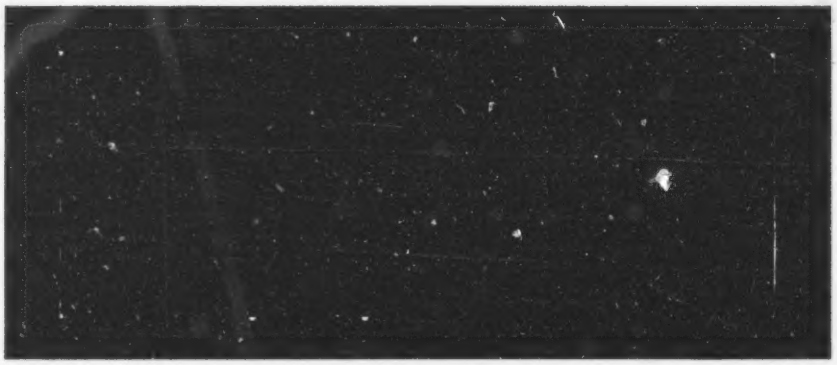

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OCCASIONAL PAPER SERIES - SCIENCE
PAPER 11 - RESEARCH ON
CONCEPT LEARNING: AN ANALYSIS

by

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SCIENCE, MATHEMATICS, AND ENVIRONMENTAL EDUCATION INFORMATION REPORTS

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Editors

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RESEARCH ON SCIENCE CONCEPT LEARNING: AN ANALYSIS

by

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INTRODUCTION

A major research effort in science education focuses on the cognitive domain. Evidence of the level of concern for assessing which science concepts students of various characteristics can learn and how they learn these concepts is reflected in the amount of financial support the U. S. Office of Education, institutions of higher education, and various foundations have provided to support program development and experimentation in this area. Further evidence of the importance of this research area is indicated by the fact that the U. S. Office of Education has seen fit to establish a Research and Development Center for Cognitive Learning.

It is not the purpose of this analysis to report the results of every study directly or remotely connected with the assessment of students' attainment of science concepts. Rather this paper is written to convey to the producers and consumers of research on science concept learning what appears to be the state of the art. Thus, selected studies are reported in this paper; a representative sample of the nature of the work completed on the various facets of science concept learning.

The results of the analysis should indicate the institutions where much of the research has been and is being done, researchers, subject areas and the nature of the problems being pursued, and the relationship of concept attainment to cognitive abilities. Recently completed studies will not be included in the analysis. However, periodic updating of research analyses such as this will permit previously omitted and newly completed studies to be analyzed for their contributions to the improvement of science concept learning.

PROCEDURE

The general sources used for selecting reports for inclusion are as follows: 1) Each of the existing science education bibliographies published in draft form from the ERIC Center for Science, Mathematics, and Environmental Education at The Ohio State University was searched for entries dealing with science concepts and research on science concept learning. In addition, microfiche, xerox materials and other materials housed at the Center were surveyed. 2) A second major source of information was Technical

Report No. 82, Concept Learning: A Bibliography, 1950-1967, of the Wisconsin Research and Development Center for Cognitive Learning. 3) Other sources included back issues of journals, dissertation abstracts, and the author's colleagues who have worked in this area. The bibliography is not exhaustive, but is intended to be representative of the scope of research in this area.

Criteria: Selection of Entries

There is a large volume of printed material regarding science concepts and science concept learning. But many publications are articles of opinion which may or may not be derived from a research base. The criteria for selecting articles for inclusion in the analysis were these: 1) The report had to demonstrate that students were involved in a situation designed to measure attainment of previously acquired concepts or concepts acquired as the result of an instructional sequence. 2) The study had to be designed to measure more than general achievement. Many reports were excluded because they did not indicate whether an attempt had been made to measure the attainment of specific concepts; they were too general. 3) The major problem of the study had to deal with measurement of concept learning. If concept attainment were considered a sub-problem, a judgment was made as to whether that aspect of the study contributed to advancing knowledge of science concept learning.

Two exceptions to these criteria should be noted. Studies designed to establish the general conceptual knowledge goals for a science program, or one of the subdivisions such as the earth sciences, were included. Literature analyses designed to synthesize the results of research of importance to those engaged in the study of science concept learning were reported.

Following the initial determination of whether a report was to be included, the report was judged on the quality of presentation.

1. The statement of the problem had to be specific.

2. The research design had to be sufficiently clear and concise that the reader could determine what had been done. The procedures had to be detailed enough that it was possible to determine whether procedure and design were consistent with the statement of the problem.

3. There had to be evidence of control of variables.

4. The results of the study had to be presented in a form which could assist the reader in answering the questions implicit in the statement of the problem; whether the data analysis was consistent with the statement of the problem and procedures employed.

5. The conclusions of the study had to have been in reference to the stated problem and consistent with the results presented.

Those reports included in the analysis have more or less met these criteria.

Other reports received brief citations. These included those where the conceptual idea was of merit but insufficient data were reported, or the style of reporting was not adequate for the reader to determine the validity of the study. In other words, the report was vague.

Some studies received bibliographic citation. These studies may have had a good conceptual idea, but there was nothing in the report which could be used to determine the quality of the research. In many instances the procedures and data analyses did not correspond to the stated problem.

One last qualifying comment needs to be made. Many journal articles are obviously derived from dissertations or other research reports. At times the journal article reports a phase of the initial research of particular significance to the research community and may be cited in addition to the initial study. When the journal article is a summary of the initial report, an arbitrary decision was made as to which report to cite.

Groups of Studies

The studies cited in this paper have been arbitrarily grouped for convenience of reporting. The general characteristics of each group are described below. The major criterion used in making the categorical assignments was the author's interpretation of the implied intent of the research.

1. Cognitive Development: These are studies where the major problem has been to make a general assessment of the cognitive development of the learner rather than expressly determining his attainment of specific science concepts. When science content (demonstrations, descriptions of natural phenomena, etc.) has been employed, it has been utilized primarily as a vehicle for assessing the "stage" of the learner's cognitive development.

2. Factors Influencing Concept Formation: An attempt is made to determine the role of personal characteristics such as chronological age or general intelligence in concept formation. The intent is to assess the effect of maturation of the learner and his experience and I.Q. in determining which concepts might be included in science curricula. These factors are purported to influence what method of instruction might be more efficient in teaching selected concepts.

3. Level of Concept Attainment: These studies are designed to determine the level of attainment of selected science concepts as a result of the cumulative learning experience within and external to the school environment. The emphasis is not on how a child has acquired his understanding of the concepts but rather to determine what he has attained. The results help to establish a set of expectations for initiating formal instruction aimed at developing and extending concept attainment.

4. Methodological Effects: In these studies a specific instructional sequence(s) has been designed to teach selected science concepts to learners at one or more grade levels. An estimate is made as to whether children at the specified grade levels can learn the concepts by exposure to a particular methodology.

5. Methodological Comparisons: This class of studies is conducted to measure concept attainment or concept development. Various techniques of instruction are employed to determine which is more effective.

6. Curricular Content: Classroom teachers, science education specialists, scientists, and others have been asked for their judgments regarding those concepts that are desirable for inclusion in the science curriculum. Often judgments as to where these concepts might be appropriately taught are made.

7. Instrument Development: In this type of study science concepts are employed as a vehicle for constructing and refining instruments. A particular teaching strategy may or may not have been employed. Devices for assessing concept attainment result.

8. Reviews and Models: Studies in this group represent theoretical postulations about the nature of concept learning and attempts to develop models for assessing concept attainment.

COGNITIVE DEVELOPMENT

Some of the earliest investigations pertaining to the nature of children's cognitive development were those conducted by Piaget (106, 107). These studies and others reported by Piaget (108) and other investigators are included in this paper because they characteristically utilize demonstrations of natural phenomena as a means of obtaining data regarding a variety of children's verbal and nonverbal behaviors. In addition to

their contributions to general theory of cognitive development, they often shed light on the development of major science concepts such as causality, weight, and volume. They also contribute to improved understanding of children's ability to observe, classify, and conserve examples of cognitive skills apparently prerequisite to the attainment of many science concepts.

Piaget's basic technique was to demonstrate a natural phenomenon to a child and conduct an ensuing interview centered around the child's observations. A major conclusion from these studies was that there are general stages of concept formation characteristic of children of particular ages and that concepts of a particular kind (e.g., life) evolve in a definite manner. These general stages are:

1. sensory-motor or pre-verbal (0-2 years)
2. pre-operational (2-7 years)
3. concrete operations (7-11 years)
4. formal operations (11-15 years)

While Piaget concluded that these are definite stages in cognitive development, he recognized that there is not a set age at which children pass from one stage to another (109). Many factors are involved including maturity, experiences and the cultural milieu.

With respect to many different concepts, Piaget defined the successive stages through which each concept evolves and linked these with age. He classified concepts of causal relations into 17 different types.

Conclusions from studies by Deutsche (36) and Russell and Dennis (128) tend to contradict Piaget's earlier postulations about the nature of children's cognitive development. Deutsche administered two tests of causal relations to 732 children fairly equally distributed among Grades 3 through 8. The first consisted of the demonstration of 11 physical phenomena where the child was asked to explain what he had observed. The second was composed of 12 verbal questions, but not as varied as those of Piaget. Three conclusions were drawn: (1) When all answers were classified according to Piaget's taxonomy for causal thinking only four types occurred frequently enough to warrant further analysis; (2) no evidence exists that children's reasoning develops by stages; there was a gradual progression in answers with advancing age and all answer types were spread widely over the age range; and (3) evidence was found of specificity in children's causal thinking as opposed to a general level of thinking. Russell and Dennis' procedure consisted of a questionnaire relating to 20 objects, some physically present, some visible outside the room, and others presented verbally. Criteria were established for classifying answers into Piaget's four stages and a no-concept stage. The population consisted of 385 children ranging in age from 3 years to 15 years 6 months. The results indicated that it is probable that individuals pass sequentially through the stages. However, all stages were present at every age instead of being discretely packaged within given age levels.

Another clinical study by Huang (56) was concerned with children's explanations of strange phenomena. These phenomena, which included illustrations and tricks as well as direct problems were demonstrated to 40 children ranging in age from 4.8 years to 8.11 years and to 11 college girls. The majority of the explanations indicated possession of naturalistic physical concepts, some very simple. The frequency of occurrence of answers categorized as finalistic, magical, moral, animistic, artificialistic, or mystical causality was slight. The infrequent use of this type of response in contrast to the findings of Piaget, was postulated to be due to cultural differences between the subjects and an absence of questions pertaining to the stars, winds, etc.

Oakes (95) sought to determine the nature of children's explanations of natural phenomena. Data were collected by individually questioning 153 children from grades K, 2, 4, and 6. His work differed from that of Piaget. He analyzed the nature of the responses themselves rather than attempting to interpret the workings of the child's mind. Data contradicted the notions of many psychologists, especially Piaget, that the nature of the child's mind is such that instruction relating to natural phenomena is largely futile. Results indicated that the 17 types of explanation of Piaget were not usable. He classified responses as physical or materialistic, nonphysical or nonmaterialistic, and failure to explain. There was a definite increase with age in the frequency of occurrence of physical explanations. In addition, all types of answers were given by all age groups, and each subject gave a wide variety of explanations. There was no evidence of definite stages being characteristic of definite ages. In contrast to Piaget's findings, the bulk of the answers was naturalistic.

The results of studies by Isaacs (61) and King (70) also contradicted the early findings of Piaget. Isaacs felt that Piaget's conclusions regarding mental stages were not borne out by her data. King's findings were based on working with 1,235 children, ages six to eleven. In discussing the part of his study involving the distinction between animate and inanimate things, he stated,"...there was no evidence of Piaget's stages of development but only a gradual development of the reasoning processes by more systematic organizations of concepts." Based on findings relating to sky and night, he concluded: "Experience in and out of school and a vocabulary increasing with age seemed to be the main factors that determined the types of answers given by boys and girls..." Both Isaacs and King concluded that the definite stages alluded to by Piaget did not exist; however, there was a gradual progression in learning with age and the same child often exhibited varying types of behavior.

Other investigations have also created doubt about the existence of definite age stages in concept formation. Welch and Long (157) gave subjects, whose ages ranged from 42 to 83 months, tests that required them to apply previously-learned concepts. The number of subjects who passed the tests increased with age, but there was no evidence of definite stages.

The cognitive development studies have been conducted continuously over the years with a notable increase in emphasis on science concepts

and related process activities. Science educators have taken to applying Piagetian techniques to the study of the development of science concepts. Other psychologists' and educational psychologists' work on learning theory is also having marked influence on the study of children's cognitive development as it pertains to science. The descriptions of studies which follow are of this variety. Many of the studies look more like learning theory studies than science education studies, but the attempt is made to better understand the development of specific science concepts or process skills fundamental to learning and understanding science. In contrast to the earlier studies, more is known about the child's school science experience. In some instances the effect of a specific learning package has been studied for its influence on the growth of specific concepts and process skills.

Many studies associated with specific science concepts are not necessarily conducted to determine students' attainment of the concepts but rather, as in the Piagetian studies, use science concepts as a vehicle for measuring children's cognitive development. Studies with younger children heavily emphasize the ability to observe, sort, or classify. The studies shed some light on the development of the science concepts but the methodology is more aligned with the assessment of cognitive development than with the measurement of concept attainment.

Raven (114, 116) and Popp and Raven (111) reported studies dealing with elementary school children's classification abilities. In one of Raven's studies (114) a set of sequentially articulated exercises was designed to facilitate the classification abilities of second and third grade children. The intent was to determine congruence and create models and patterns. The student instructional booklets, involving 12 rules originating from Piaget's analysis, led the children from a visual organizer to a verbal rule to a problem to solve (a diagram). Children in grade three had greater success on the hierarchial classification levels than children in grade two. In the other (114) study, 160 students in kindergarten through grade three were presented with eight different concept attainment tasks; each presented twice, followed by a criterion task. The tasks were grouped: Compensation--mass, speed, momentum; Transitivity--momentum, speed, mass; Coordination--speed, mass. The general results were in close agreement with Piaget's findings. Differences were found among tasks within the dimensions of Inference Pattern, Goal Object, and Percept Tasks. The obvious differences were among the transitivity, compensation, and coordination inference pattern values. It was concluded that the achievement was a product of maturation and dimension values.

The Popp and Raven study used instructional booklets to teach twelve rules in a classification skills program. Two formats were used - a constructed response where a child drew an object or class and a multiple response where a child selected from one of three options - related to the ability to produce responses or construct responses. They found that having the program format and the response format the same enhanced performance.

Others have conducted studies dealing with young children's classification behavior. George and Dietz (42) investigated the system(s) used by urban and suburban children in grades one, two, and three in classifying pictures of bottles. The task was to find one attribute the same for two bottles and then repeat the procedure on another attribute. Significant differences were found in the number of classes using different properties in both the urban and suburban groups. Approximately 70 percent of the students used only one property in classifying. There was a significant difference between the urban and suburban children in the use of the property of height. No grade level factor was evident in the suburban group but in the urban group children in grade one scored significantly higher on identifical properties and grades two and three on the height of the bottle.

Lowery and Allen (80) also studied children's classification behavior. A group of first graders were grouped on the basis of sex and socioeconomic status and given a non-verbal test of resemblance sorting tasks of five types. General results showed children classifying on the basis of single attributes rather than two or more attributes, classifying best on shape and least on size, and girls generally doing better than boys, except in the low SES, where boys did better than girls. The most obvious girl-boy difference was on the property size. The results suggested a hierarchial sequence of difficulty with variations involving low SES children.

A scalogram analysis of classificatory behavior was conducted by Allen (5) to determine whether a classificatory hierarchy exists, i.e., whether passage of one task in a sequence always implies passage of all the tasks of a lower rank in the sequence. Students using SCIS (Science Curriculum Improvement Study) materials were compared with students in a non-SCIS program on an 11 item classificatory hierarchy. Data were analyzed by both the Guttman and the Lingoes Scalogram procedures. The groups did not meet the criterion for orderliness, but there did appear to be an order of groups of task skills.

Elementary school children's use of classificatory dimensions and rules was also studied by Weinbrenner (156). Children of varying sex, ability level, and neighborhood background were asked to group science-related objects. Three-fourths of the group subsets were based on science classificatory concepts, fifty percent of the subsets were based on gross characteristics such as size, and ninety-five percent of the subsets were based on one attribute. The results were similar for the independent variables, with some irregular increases across grade level.

Several studies have also been conducted on the development of children's observational skills. Zeitler (163) reported a study with 30 three-year-olds of racial and SES mix. Following a pretest, students were presented with ten activity-centered property lessons, each lasting from one to three weeks. He found that observational skills can be taught. Boys and girls used similar senses and made similar observations but in this instance boys improved their skill more than girls.

Raven and Strubing (119) and Allen (2, 4) studied the observational skills developed in association with use of existing science curricula. Raven and Strubing gave second grade students training with one or two units of the Frostig Program for Development of Visual Perception prior to studying the SCIS unit on Relativity of Position and Motion. Students were assigned to groups receiving training on Spatial Relations, Visual-Motor Coordination, or a control group. Instruction was followed by a posttest. Both treatment groups scored higher than the control group, but there was no difference between treatment groups. It was concluded that training in general perceptual abilities helps, particularly at the interfaces of Piaget's Stage I and Stage II. The type of training was not considered as important as receiving some training.

Allen (2) reported that a group of first graders using SCIS, when compared to a group of students not using SCIS, were superior on serial ordering and demonstrated more exploratory behavior. In a later report (4) he indicated that the SCIS children did better in the use of fine characteristics and on the handling of materials, but that the groups were similar in describing materials on uses versus properties.

Ritz and Raven (124) measured the effects of structured science experiences (S-APA) and visual perceptual instruction (Frostig) on reading readiness, visual perception and science process skills. Treatment groups consisted of a group receiving a portion of segment A of S-APA, a second group who completed the S-APA materials and then received portions of the Frostig battery, and a third group who received the Frostig materials only. Students were tested at the completion of the S-APA work and at the end of the instruction with a test adapted from the S-APA materials. There was no difference in reading readiness at either test point. Higher process scores were found at the first test point and higher perceptual scores were found at the end points. Ritz and Raven concluded that including science in the primary program would not detract from reading readiness.

Gillespie (44) gave a group of five, six, seven, and eight-year-old upper-middle-class children four tests associated with leaf morphology--picture association, leaf discrimination, generic association, and communication ability. There were no differences between boys and girls on any test but there was a sharp break between the five-year-olds and all older age groups.

Scott (134) presented a group of fifth graders with an inquiry training program designed to improve focus on "fine" structure in categorization and to lessen emotional responses in categorization activities. The students were followed for three years. Based on results from the Sigel Cognitive Styles Test, he found that verbal fluency and flexibility were increased, attention to detail became more acute, and there was a movement away from emotional and locational responses toward inherent classificatory attributes.

Bybee and Hendricks (27) reported the results of a feasibility study using science concepts to improve language development. After ten weeks of

instruction the seven preschool children involved had learned selected science concepts and had increased their vocabulary by 35 new words.

Two studies dealing with Piaget's 16 binary propositional operations were conducted with high school students. Lengel and Buell (76) randomly selected lower SES students from grades seven, nine, and twelve and presented them with a triple pendulum ring-stand set-up with varying string lengths and bob-weights. The students were to find what dependent variable(s) were related to the independent variable of midpoint velocity. "Think-out-loud" protocols were recorded. There was a growth in logical operations "exclusion" between grade seven and grade twelve. Eighty percent of the grade twelve students were conservers but no conserver reached quantification. All were above Stage I. The effects of IQ and SES were questionable and there was no sex difference in the rate of conserving. Buell and Bradley (25) worked with 56 students in first year chemistry and 14 students in advanced placement chemistry. Prior to instruction in the concept "solubility," students completed a test of graph interpretation. Following two weeks of instruction, they answered a set of directed questions about the same graph but had available a table of solubilities. Results of the first tests showed several students at the level of logical operations. After instruction not many students were at the logical operations level and those who were on the pretest exhibited decreased scores.

Comments

The studies reported are characteristic of the research on cognitive development which has import for the science educator interested in studying the nature of science concept learning. Of note is the heavy emphasis on work with primary and elementary school children and the recent and increasing emphasis on the development of such process skills as observation and classification.

One consistent finding in the studies is that cognitive development is developmental. General stages or patterns of development may appear when one sums across a total population, but individual studies continually demonstrate that these general patterns should not be used in a predictive sense for individuals and subgroups with similar characteristics. This is especially true because many times little is known about the range and quality of experience of the subjects under study. Nevertheless, the studies,singly and collectively, can give us some indications of what to expect when attempting to structure the science curriculum and when planning for the development of instructional sequences.

Factors which have shown up as influences on the cognitive development of children include socio-economic status, vocabulary, the nature of the concept, the class of concept, age, and experience, vocabulary, and culture. An examination of these factors indicates, however, that each is in some manner an indicator of the learner's experience. They indicate what amount of experience the learner has had with phenomena and what he

has acquired as a result of the encounter. Because of a wide variance in these experiences and varying abilities to learn, it is no wonder that all "stages" of cognitive development appear at all ages.

FACTORS INFLUENCING CONCEPT FORMATION

Several studies have been directed at determing what influence factors such as age, intelligence, and general cognitive development play in science concept formation. These studies indicate that there should be concern for the maturation of the learner and his experience in determing what concepts to include in the school science curriculum. These factors should also be considered in planning what means of instruction are potentially more efficient for teaching selected concepts.

Sorting tests were utilized by Reichard, Schneider, and Rapaport (121) to investigate the abilities of children to formulate concepts. They inferred that there are the concrete level (classification based on nonessential incidental features of the object), the functional level (classification based on use, value, etc.), and the conceptual level (classification based on abstract properties or relations). The functional level was quite typical of children 8-10 years of age. Long and Welch (79) also found that concepts developed from simple to more complex levels as a function of age.

Deutsche (36) found little relationship between intelligence test scores and the test scores on causal relations. Long and Welch (77) reported that chronological age is at least as important as mental age in concept formation.

The studies by Deutsche (36), Oakes (95), and Ordan (98) indicated that variations in experience determine the nature of children's concepts and their use, at least as much as do variations in intelligence. Peterson (104) found that when subjects were required to formulate generalizations about the principles of the level, performance was related more closely to grade level than to either age or intelligence.

The previously identified studies indicate the necessity for seeking those factors related to which concepts or classes of concepts can be learned by children of varying characteristics. One study of note was conducted by Myer (92). The purpose was to determine (1) which processes lead to the attainment of concepts and, (2) the conditions within the formal learning situation which affect the formation of concepts. Data were collected by analyzing the results of studies in human learning, specifically those found under the headings of concept formation, transfer of training, and problem solving. A finding consistent with those previously presented was that concepts are usually formed only after a long and gradual process of learning to distinguish between examples and non-examples of a concept. An individual's ability to learn a particular concept and his capacity to interrelate concepts appears to be derived from an interaction of broad experience and innate intelligence. The manner in which one learns a concept may determine his use of the concept in a new situation, and an incubation period following intensive study may facilitate learning. Knowledge

of the structure and vocabulary of one's native language also facilitates conceptual learning. A major implication from this research was that the nature of the learning environment fostered by instructional personnel is a major factor in learning science concepts.

Lamb's study (75) dealt with teacher knowledge as a potential influencing factor on the nature of the learning environment. He prepared a mastery examination for 50 chemistry concepts. This test was administered to 601 college freshmen entering chemistry classes and to 78 of their high school chemistry teachers. Significant correlations were found between the students' scores and the teachers' scores for 13 of the 50 concepts.

Studies by Sharo (136), Griffin (47), and Scriven (135) were conducted to determine which factors might affect the attainment of science concepts. No instructional sequence was employed prior to data collection. Sharo found a significant correlation between scores on two of four visual spatial relations tests obtained from the Psychological Corporation and the Educational Testing Service and the scores on the physics achievement examination of the College Entrance Board (60 high school students). The results of Griffin's study indicated that there are selected industrial arts experiences which can contribute to the understanding of certain science concepts.

Scriven (135) studied the proportion of concept types--structure, process, or quality in meaning--used by fourth through ninth graders in explaining scientific terms. A panel of judges categorized a group of scientific terms as essentially structure, quality or process in orientation. A group of 720 students was presented with one word from each of the three categories and asked to explain what the word meant and also given a formal instrument where each term was followed by a structural, a process, and a quality explanation. The results of the two tests were compared to determine the differences between the invented and the selected explanation. Students in high and medium IQ groups used mainly structure and process type explanations with the use of process explanations increasing proportionately as students advanced in grade groupings. The use of quality explanations was significantly greater in fourth and fifth grades than in the eighth and ninth grades. Intelligence and grade level appeared to exert the most influence upon the concept usage. Scriven suggested that the types of explanations used by students differed according to whether they were inventing or selecting explanations.

The studies conducted by Brusini (24), Pollach (110), and Murray (90) measured the relationship between concept attainment and various characteristics of children after a formal instructional sequence had been presented. Brusini's study was designed to test the ability of children in grades three through eight, with varying IQ's, to form the geologic idea, cycle of stream erosion. A discrimination method employing a sorting test technique was used to study concept development. A major conclusion was that the amount of direction given the child has more effect on his learning than does his age. However, an increasing proportion of the sample was able to form the concept as age increased. Those children who were

successful in forming the concept were those who were able to make inferences from the pictures presented to them. All children not able to form the concept conceived the pictures only in terms of what was immediately seen.

In Pollach's study a film was presented to a group of 117 fifth grade students (experimental) and a group of 50 fifth grade students (control). A test was then administered which measured students' possession of knowledge and their ability to answer questions of the comprehension and application varieties. Scores on the knowledge test and the tests of intelligence and reading ability were correlated with the scores of the comprehension and application. Results indicated that there is reason to question the implied mutually exclusive character of items measuring learning levels classified as knowledge, comprehension, and application. Knowledge was a better predictor of behavior on tests of comprehension or application than was a measure of reading ability or intelligence.

Murray's study was designed to test a model for the interpretation of concept formation. The subjects consisted of college students enrolled in introductory botany and principles of biology courses. The major conceptual idea was plant growth. Tests designed to measure information store (recall of facts, observations, and experiences within the course structure) and information processing or analytical ability (manipulation of data) were administered at the end of the first, third, fourth, fifth, sixth, and tenth weeks of the period of study on plant growth. The measurable increase in understanding of the concept after a period of ten weeks was slight, most of the increase being attributed to information gain. However, it was found that students with higher analytic ability were able to acquire higher information store. Murray suggested that research focus on preparing analytic approaches to instruction rather than concentrating so heavily on the measurement of performance after an instructional sequence designed to affect learning.

Studies designed specifically to determine grade placement or selected science concepts apparently are based on the assumption that children are able to generalize. Croxton (22) attempted to determine whether children in grades K through eight were able to formulate and apply a principle after exposure to an essential experience base in the form of demonstrations or directed play. He found that children at all grade levels were able to generalize, but the children in the higher primary, intermediate, and junior high school grades were considerably more successful than were those in kindergarten and the lower primary grades. He inferred that this was not so much due to superior mental ability but rather to additional experience acquired by the children.

Baily (13) studied the extent to which pupils at various grade levels and with differing mental abilities were able to attain an understanding of selected aspects of the concept "power" included in a science unit presented to pupils in grades six through nine. He found that only boys of high mental ability were consistently able to do satisfactory work on the unit while girls of high mental ability exhibited irregular achievement. Both boys and girls of low and middle ability groups were unable to develop satisfactory understandings.

The effect of manipulation of materials on concept attainment was studied by Butts (26). He found that manipulation of materials did not necessarily improve concept development but that children needed other experiences and guidance in order to develop concepts. The potential of children to form concepts was determined by the amount and quality of the previous experiences, and by their cognitive abilities. These factors will determine the use of the manipulative activity in the refinement or development of new concepts. In a study comparing first grade children's development of conservation and transition, Lepper (78) found that differences in the success of black and white children, stratified on the basis of low, middle, and high ability were attributable to experiential background.

Read (120) examined more than 20 grade placement studies involving conceptual ideas in the physical sciences. The usual technique was to administer a pretest, follow it with demonstration of a single idea accompanied by oral discussion, and immediately posttest. The studies were conducted in several different schools with children at more than one grade level. He concluded that both grade level and intelligence were factors in learning the respective conceptual ideas. He also concluded that most of the basic science ideas could be learned by children at lower grade levels than those at which they had been traditionally introduced. He attributed the increased learning with advancing grade level to additional experience rather than to innate intelligence.

Another group of recent studies in this area is somewhat similar to methodological studies but the intent is different. Whereas in the methodological studies the instructional method is assessed in reference to an induced achievement level, here an attempt is made to ferret out the fine structure of underpinning factors which might influence the attainment of selected concepts or classes of concepts.

Harding and Jones (49) used three types of interviews to determine the effect of the child's perception of the interviewer on the stage of development of physical and moral explanations for natural phenomena. Children of ages five to ten, 450 in number, were assigned to three groups. Children in Group 1 were interviewed by a man called Mister, children in Group 2 were interviewed by a man called Reverend (attired in a black suit and clerical collar), and children in Group 3 were interviewed by telephone. The results were similar to Piagetian stages in development but there were no significant differences in the stages of development between the three groups. An interesting side result was that teacher misinformation about science concepts was reflected in the children's responses.

The effect of the form of instructional material on Lebanese children's conservation of weight was reported by Za'Rour (162). The three types of materials used in the conservation tasks were plasticene balls, rubber bands, and a weather thermometer. A general increase in conservation with age was found, notably higher when plasticene balls were used. Boys were more successful than girls. The level of significance for these differences was .01. Students at each successive grade level earned higher scores than did students of the preceeding grades.

Another factor apparently influencing science concept attainment is the ability to perform subordinate skills for the target concepts. Examples of this kind of study are those conducted by Capie and James (28) and Okey and Gagne (96).

Capie and James (28) identified a list of prerequisite skills subordinate to the concepts: density and specific gravity. Students were required to predict whether a substance would float in a liquid when the intruding substance was a liquid, a regular solid, an irregular solid (S.G.>1), or an irregular solid (S.G.<1). The respondents included students from first grade through senior high school physics students. Ability to perform the tasks was followed by a brief multiple choice test on Archimede's principle, specific gravity, density, and buoyancy. Many dependency ratios were found but there was uncertainty about the validity of a task hierarchy. One source of the problem could have been the instrumentation. Okey and Gagne (96) developed a task analysis for solubility product consisting of 15 subordinate skills. Work in a pilot study and a subsequent revision indicated that adding instruction on the subordinate skills helped in completion of the performance task but that the relationship was not linear. Construction of the task analysis had, however, assisted in location of areas of difficulty.

Another study concerned with task analysis in the identification of learning difficulties in science concept attainment was reported by Swartney (145). She analyzed areas in which students enrolled in the CHEMS program were unsuccessful. Students had difficulty formulating concept definitions and were further hindered by deficiencies in substantive background, mathematical skills and concepts, and understanding of abstract and theoretically derived concepts. They were also limited in their understanding of the particulate nature of matter.

Concept attainment also appears to be influenced by possession of subsuming concepts. Some aspects of these studies are similar to the work on task analysis but the estimates of underlying knowledge or skills are more generally assessed than in task analysis. Three such studies are reported here. Kuhn and Novak (73) used the subsuming concepts of Biological Organization and Homeostasis as organizers with college freshmen and sophomores, mostly females, enrolled in a biology course for elementary school teachers. The approach was partially based on Feigenbaum's model of the memory system and Herbert's theory of apperceptive mass. Data, including retention data, were gathered over a period of two years. Time and knowledge input were controlled. In both the study in which the organizer preceeded the treatment and the one in which the organizer was coupled with partial sequencing of material in the learning passage, there was an impact on the outcomes.

Ring and Novak (123) reported the influence of facts and subsuming concepts on new learnings in beginning college chemistry. They considered the ability of the learner to assimilate new information into his existing cognitive structure. The subject's cognitive structure (chemistry) was based on results from the ETS Test of Specific Course Objectives and

achievement was measured with a locally developed examination. Course achievement varied linearly with the numbers of facts in the cognitive structure and with the number of relevant subsuming concepts. However, where there were many facts without subsuming concepts, there was low achievement. Generally, the possession of subsumers was a better predictor of success than possession of facts when the amount of facts or subsumers was low. Ring and Novak concluded that cognitive structure in chemistry was a better predictor of success in chemistry than were measures of general ability and that both facts and subsuming concepts were needed for high achievement.

The success of undergraduate college students in chemistry was also studied by Graber, Means, and Johnston (46). They classified the students as good organizers or poor organizers based on the results of an instrument designed by one of the investigators. Three treatments were administered: advance organizer followed by a learning passage, learning passage followed by an advance organizer, and a historical nonorganizer followed by a learning passage. There were no treatment main effects or interaction effects, but the good organizers scored significantly higher than the poor organizers. The authors felt that the results of their study contradict the results of the Ausubelian work of the early sixties (materials were identified).

In addition to studying the effect of learner variables on the outcomes of learning, studies have been conducted to determine the effect of instructor's teaching style on learning outcomes. Sayer, Campbell, and Barnes (129) selected three instructor-centered and three student-centered teachers of introductory college biology by applying a Flanders classification to video-tapes. Student achievement was measured for low cognition (Bloom: 1.11, 1.12, 1.20, 1.30) and high cognition (Bloom: 2.0, 3.0, 4.0). The tests were balanced for course content and levels of cognition. No significant differences in achievement were found between the groups.

Comments

Those factors which are identified most often as influencing the development of science concepts fall predominantly in the categories of experience and cognitive abilities. Specific factors which were identified were maturation, experience, chronological age, grade level, language, the learning environment, intelligence, directions associated with instruction or testing, spatial relations, ability to organize, and teacher knowledge and misinformation. In addition to reinforcing the previous finding that much of the ability to form science concepts depends on the breadth and quality of experience and certain cognitive abilities and prerequisite skills, there was also support for the general notion that children cannot handle abstractions or generalize until they reach the ages represented in upper primary and lower intermediate elementary school.

One finding of particular interest is the conflict as to the influence of intelligence on the development of science concepts. Part of this difficulty seems to be in the design of the studies. As planned, there may

or may not have been a reason for intelligence to be expected as an influencing factor. The investigators have not made provision for planned comparison but rather have gone to after-the-fact correlation analysis--therefore, we might expect differing results. Where intelligence does exhibit a contributing effect, there is reason to suspect that the amount and nature of the experience the learner has had result in an interaction effect rather than a main effect.

Another finding of interest is the fact that "knowledge" possessed contributes more to the variance in results than do factors such as reading ability or intelligence. As for reading ability, one could not expect it to contribute much unless the ability to read influences the ability to receive input from the instructional materials. Then, this would be influenced by the amount of experience the learner had had. Experience seems to be the underlying factor. This is backed up by those studies where subordinate skills, subsuming concepts, and mathematical skills influenced the results of the concept learning. Even factors such as manipulation of materials only become a contributing variable after a wide range of experience has been obtained.

The studies in which the ability to distinguish between examples and non-examples of a concept and studies in which the ability to formulate concept definitions are influencing factors point out the necessity to give more consideration to the nature of the concepts being studied as well as to those factors related to the learner's experience and ability. The structure of the discipline and the class or nature of the concept should not necessarily be the dominant forces in structuring the learning situation but cannot be ignored either. It is also highly possible that the learners are penalized by a lack of understanding of the nature of the formulation of knowledge.

In the area of testing, there is reason to question whether the categories of the Bloom taxonomy are mutually exclusive. Further support for this contention will appear in later sections of this report. Whether the learner is asked to invent or select a response also appears to influence the results of concept attainment measurement.

LEVEL OF CONCEPT ATTAINMENT

Pre-Assessment Studies

This class of studies aids in establishing curricular content by determining students' understandings of concepts and students' abilities to explain natural phenomena. Studies are designed to determine what level of understanding or mastery of selected concepts has been attained by students of varying ages, experience, or particular personal characteristics. Data are usually of two types: those in which paper and pencil responses are solicited or some type of performance, demonstrated skill or verbal response to a situation or group of questions is required; and, those in

which respondents are confronted with a demonstration or experiment after which they demonstrate in some fashion their understandings. The usual outcome of this type of study is an estimation of an appropriate point to initiate teaching science concepts.

Conceptual understandings measured in these studies are an accumulation of experiences, both internal and external to the school environment. Results of the studies indicate where and how it might be fruitful to begin instruction aimed at development or further refinement of the selected concepts. Generally the data-gathering technique is similar to the Piagetian type clinical interview or some minor variation thereof. One method is to ask strictly verbal questions. A second is to ask questions that are presented non-verbally. The third technique is to carry out simple activities or demonstrations in the child's presence and then ask him to explain the phenomena he has witnessed. The results are usually reported related to the projected grade placement of science concepts. Conclusions are often drawn about the nature of children's cognitive development.

Often pre-assessment of science concept learning is carried on as an adjunct to another problem. For example, the secondary purpose of McCarthy's study (84) was to determine at what grade level selected conceptual ideas related to the concept "work" could be successfully taught to elementary school children. Three experiments related to the level, the pulley, and the inclined plane were presented to children in Grades K-4. The results indicated that the concepts expressly embodied in the performance of the experiments were suitable for students in the second grade.

Kuse (74) interviewed primary grade children in three Wisconsin counties to assess their attainment of selected astronomy concepts. She also sought information about the sources of the children's information for formulating these concepts. She found that children discussed many topics not presented in texts for elementary school children and that the information presented in many texts was already known by the majority of the children in the sample. Children expressed their understandings of the concepts as descriptions of the appearance of objects more often than giving explanations of causes of phenomena. Results also indicated that children hold partially developed concepts about astronomy for which they do not have an appropriate vocabulary; certain words used to describe objects in space have very different meanings for different pupils. Children used a large variety of sources for gathering information with books ranking highest and direct observation a close second.

Yuckenberg (161) assessed the nature of certain astronomy concepts attained by first grade children prior to instruction. Specific concepts included sun, moon, day, night, and gravity. Children were asked ten questions about these concepts. There was some evidence that children's immediate knowledge had been extended to include many conceptual understandings held by adults. Yuckenberg concluded that it was possible to lay a foundation in first grade for much of the knowledge essential to astronomical understanding in the later grades. The children's interest in the concepts indicated that astronomy might be taught at an earlier age.

Another study related to children's understandings of selected science words (concepts) was conducted by Howards (54). A multi-meaning word test was constructed and administered to children in Grades 4, 5, and 6. The words used were on all existing scientific word lists and were considered easy or familiar words. The results indicated that a developmental pattern exists in children's understanding of the various word meanings. Older children knew more meanings of these multiple-meaning words than the younger pupils. The differences in scores between grades were statistically significiant and significant correlations were found between the children's scores on the multiple meaning word test, IQ, and a reading sub-test score from the Iowa Silent Reading Tests. No differences were found between test scores for boys and girls.

Kantz (67) prepared an electronically recorded interview to solicit children's responses which were to review their understandings of selected science terms and principles. A total of 68 terms and principles of physical science were incorporated into demonstration interviews related to matter, energy, heat, light, gravity, and earth. Presentations were made to 60 children, 20 each in Grades 1, 3, and 5 in 1950 and 60 matching children in 1964. Matching was done on the basis of chronological age, sex, grade in school, intelligence quotient, and social class position of the parents. For the two groups a total of 532 different ideas related to the terms and principles were found, with 372 similar ideas revealed by children in both the 1950 and 1964 groups. Seventy-four conceptual ideas were found in the 1950 data but not in the 1964 data. For 58 of the 68 terms and principles older children were more correct in their understandings. For 41 of the 68 terms and principles children in the 1964 group were more scientifically accurate. The 1950 group was more accurate on 20 of the 68 terms and principles.

Studies pertaining to beginning primary children's understanding of selected concepts have been conducted by Helfrich (52), Olmsted (97) and Rush (127). Helfrich analyzed the content of four elementary science texts and identified conceptual ideas, common to all four texts, capable of being presented pictorially for testing purposes. A total of 88 entering kindergarten children were tested individually in each of four sessions during their first month of school. In general the children were able to name the processes, pieces of equipment and animals presented to them, and had most success in naming animals and least success in naming pieces of scientific apparatus. Often the children stated the function of an object without knowing its name. They were more successful when presented with concrete stimuli than when only having a verbal conversation with the investigator. Apparently the children were more knowledgeable in science than their language permitted them to communicate.

Olmsted (97) analyzed five recently published first grade science textbooks and found 11 concepts in common. An interview schedule of 18 questions, including 30 different ideas inherent in the 11 concepts, was administered individually to 140 beginning first grade children randomly selected from classrooms in a large metropolitan area. Sixty-eight percent of the children's responses to the questions were correct. No

differences were noted between the boys and the girls, although there was a higher proportion of items on which boys achieved higher scores than did the girls. Children who had previously attended kindergarten scored significantly higher than children who had not. The results indicated that more physical science concepts were appropriate for the curriculum than were currently being included.

Rush's study (127) was designed to identify preschool children's understanding of "living" and "non-living" prior to and following instruction. In addition he sought to determine whether there was a relationship between concept development and selected characteristics of growth and development for the children involved. The five children involved in the study received a verbal test associated with various pictures and objects prior to receiving 25 instructional periods, each 50 minutes in length. He found that children had formed concepts of "living" and "non-living" prior to instruction. After instruction the children were able to refine, expand, and transfer their previously held understandings to a new situation. Primary criteria for differentiating between "living" and "non-living" were concerned with locomotion, growth, food intake, and reproduction.

The ability of students to define or explain certain science vocabulary is often utilized as a measure of concept attainment. One such study was conducted by Shoemaker (137). Student's understandings of 20 science words were determined by constructing two forms of a two part science inventory, one form for junior high school students and the other for senior high school students. Each form included three true statements about each of the 20 words, expressing ideas with various degrees of complexity. Part I required that students indicate their agreement, disagreement, or indecision about each statement. In Part II, they were told to assume that all statements were true and were asked to rank each of the three statements in a set according to their importance. Boys scored significantly higher than girls in recognizing true statements related to biological science. The sex of the pupils, the grade level, the science course studied, and the size of the school district appeared to have little or no effect on pupils' opinions about which statements were most important. No correlation was found between the relative complexity of the statements and either the pupils' recognition of the "truth" of the statement or their ranking of its importance. There was a lack of overall gain in science concept formation as the pupils progressed in grade level. Shoemaker noted that many science concepts were learned from out-of-class experiences.

In a study on children's causal reasoning, Deutsch (36) found a high relationship between grade in school and a child's score on tests of explaining natural phenomena. Oakes (95) used a similar technique. Children were asked verbal questions and other questions which centered around the demonstration of a natural phenomenon. He found that there appeared to be a general understanding of essential relationships which increases with age, as reflected by grade level. McNeil and Keislar (87) conducted a study in which a group of 72 pupils randomly selected from the lower elementary grades were interviewed individually to determine their conceptualization of condensation and evaporation. They found that explanations

based on a description of some feature of aspect of the phenomenon occurred almost without exception. Explanations of a theoretical nature were extremely rare, although occurring more frequently at the third grade level than at the first grade level.

Silano (139) presented pupils in the first and third grade with magnets and metal strips and observed as the children manipulated the apparatus. This was followed by a period of free discussion during which records were made of all pertinent discussion among the children. Younger children were more concerned with what happened rather than why it happened. It was concluded that science instruction in the early grades should be chiefly in the form of direct experience and that one of the most appropriate ways to evaluate children's concept formation is to listen to their verbal expressions without interruption.

More than 1200 children were given a schedule of 70 questions by King (70). Questions dealt with an estimation of length, time, and direction; volume, weight, shadows, night, and sky; and growth of living things and seasons. For 24 of the questions which could be answered by non-instructional experiences, correct responses showed a steady increase with age. Concepts not easily understood without formal instruction produced confusion on the part of the children. In those instances where children gave free answers to questions about sky and night, the types of responses were spread through all age groups, no kind of response being typical of any age group. As age increased, reasoning gradually replaced descriptive words and percepts gave way to concepts.

Young (160) assessed the nature of selected understandings of atomic energy attained by children in grades 3 and 6. Seventy-five third graders were interviewed and 68 children in grade 6 responded to a questionnaire. Each test instrument contained eight items. Children's responses were classified as no answer or misconception, some information, and more complete information. He found many children in both groups giving responses related to structure and the uses of atomic energy. It was obvious that there was a substantial impact due to TV, newspapers, and adult conversation. There were also many misconceptions.

Grade and age differences in children's experiences with and explanations of magnetism were measured by Haupt (51). He also attempted to determine whether children's development of the concept magnetism paralleled the historical development of man's knowledge of the area. Twenty-five children from grades 1 through 7 were questioned individually while they played with magnets and other materials. Children in the lower grades had attained the concept at a level equivalent in complexity and maturity to that of children in the higher grades. Based on the data, he concluded that "this study of parallels of children's thinking with that of the race reveals primitive ideas that are used to conceptualize the raw data of experience."

Inbody (59) presented a series of natural phenomena to 50 kindergarten children to determine their understanding of the occurrences. Twelve were presented by demonstration, two by pictures, and two by verbal description. The children were asked to predict what would happen to given materials under certain circumstances, to describe what happened in a particular phenomenon, and to explain the cause of the occurrence. He concluded that there was little doubt that the nature of children's thinking changes with maturity and experiences. Of particular note was the conclusion that the kind of thinking that a child can do at a give time places limitations on the type of instruction from which he can benefit. Children were able to understand cause and effect relationships, but the data also indicated that an adult's logic was often meaningless to children, leading to excessive verbalization which may be misconstrued as evidence of learning.

Comments

The studies described in this section have focused primarily on concepts and conceptual ideas from the area of the physical sciences. In most instances the assessment of level of concept attainment is a reflection of the total accumulated experience of the child, school and nonschool. Therefore, the results of the studies provide an estimate of where we might begin instruction as well as where we might expect to get with instruction. They provide an indication of points at which we might consider including specific concepts in the science curriculum.

As noted in the previous sections (and those to follow) the emphasis is on the elementary school child. The research has concentrated with children's development of concepts of objects, relational concepts and more abstract or theoretical concepts. Younger children's science concept development reflects a heavy preoccupation with descriptions, characteristics, and properties of objects and phenomena. The concern is more for "what" than "why." This finding is in agreement with an earlier result regarding the ability to distinguish between examples and nonexamples of a concept as an influencing factor in concept development. However, there is some indication that children in upper primary or lower intermediate grades can be induced to begin the development of some aspects of more theoretical concepts.

Children seem to be more accurate in their concepts than was found in earlier studies. They know more than is found in the instructional materials targeted for specific ages and grade levels and they develop multiple meanings of concepts as they grow older, but concept understandings vary within all ages and ability levels.

Factors which seem to penalize the children in their ability to communicate their concept understandings relate heavily to the development of vocabulary and the investigators' heavy dependence on the ability to define concepts and relate meanings. When this insistance becomes a prescription more than a means of determining how far the child has progressed,

it becomes an inhibitor to beware of. At the same time, however, use of clinical interviews, demonstrated phenomena, multiple forms of tests, and taxonomies of questions such as the Bloom categories has helped the child give a better account of himself. The studies suggest that researchers be more than just a little cautious about imposing adult logic on the young child. For example, in some studies children have been able to deal with functions of concepts without knowing the names.

Children with the greatest amount of experience have been most successful in developing the concepts, and their responses to concrete stimuli have been superior to responses to abstractions. In instances where statistically different scores have been attained by boys and girls, there is a hint that the result could be a cultural one.

Based on the results of these studies, more emphasis could be focused on the physical science concepts in the elementary school science curriculum providing appropriate recognition of the most advantageous learning environments was paid heed.

METHODOLOGICAL EFFECTS

Grade Placement Studies (With Instruction)

Some investigators interested in science concept learning develop instructional sequences to assist students at various curricular levels in learning selected concepts or conceptual ideas. They assume that the planned instructional sequence utilized is appropriate and viable instruction for teaching the respective concepts. The primary purpose of such studies is to determine whether students at a particular grade level, having particular personal characteristics, can learn the concepts as measured by the investigator's assessment technique. For example, Ashbaugh (8) designed a study to arrange in order of difficulty a series of geological concepts in the intermediate grades. A total of 256 pupils in grades four, five, and six was grouped according to high and low achievement as determined by intelligence quotient and previous science achievement. Instruction focused on a series of 30 demonstrations. Students of higher ability earned higher post-test scores than students in the low experimental or control groups. The number of concepts attained by the children was higher for the high experimental group than for the low experimental group at each successive grade level. But understandings of the selected concepts were not significantly related to socioeconomic status, age, or intelligence.

Oxendine and Read (100) prepared an instructional sequence to instruct fourth and sixth grade children in the conceptual idea "sound is produced by vibrating material." The sequence utilized a lecture-demonstration technique. The results indicated that fourth grade pupils were not ready for instruction related to this conceptual idea and pupils of a mental age eleven to twelve years could master the concepts as measured. A second study (99) was done by Oxendine in 1958 with a population of 700

children in grades four and six who again received instruction by lecture-demonstration. The results of this study led to the same conclusions as the previous study.

In 1952 McCarthy conducted a study (84) to determine the grade placement of selected aspects of the concept "work." Most children who received instruction were second graders. Some pupils from grades K, one, and four were also involved. The procedure consisted of having the children manipulate a lever, a pulley, and an inclined plane in experimental situations. Data indicated that the concepts were appropriate for inclusion in the second grade, and that mental age had a marked effect on children's attainment of the concept. McCarthy found that children could often demonstrate their understanding on apparatus even if they could not verbalize it.

The understanding of certain aspects of the concept atomic energy was studied by Reid (122). He used a multiple-choice test in a pre- and posttest situation with children in grades four, five, and six. Children in grade six achieved the highest mean score with increases across grade level noted. Children's understanding of selected concepts related to the molecular or magnetic theory of heat was measured by Harris in 1964. Following the viewing of eleven teaching tapes, a group of 74 children were asked to respond to 14 oral questions. Certain concepts were found appropriate for the fifth and sixth grades, but most of the concepts initially deemed appropriate for inclusion in the fourth grade were not understood by the children.

Following the first phase of a study designed to determine the readiness of lower elementary pupils to learn selected concepts related to molecular theory, particularly evaporation and condensation, McNeil and Keislar (87) prepared an instructional sequence consisting of 500 picture cards each accompanied by a written passage read to the pupils. The experimental and control groups consisted of six first-grade pupils, each matched on the basis of sex, intelligence, and scientific vocabulary. Instruction was given in 13 individual sessions of 10 to 15 minutes each. Students in the experimental group could answer questions dealing with context similar to that used in instruction but they were unable to generalize to new situations.

Another study concerned with the particle nature of matter was conducted by Dennis (35). Approximately 200 pupils in grades two through six were divided into high and low ability groups based on IQ scores. Their instruction consisted of a series of lessons dealing with three conceptual ideas related to the particle nature of matter. Special care was given to preventing low reading ability from interfering with the children's learning of the concepts by writing all laboratory instructions in Pittman's Initial Teaching Alphabet (I/T/A). He concluded that these concepts probably should not be introduced much below the fourth grade level and then only to high ability third graders.

Some of the most recent work on the particulate nature of matter has been completed by Pella, et. al. (102). The lessons were developed around the processes used in theory development in the natural sciences: phenomenon--mental model--mechanical model--inference. Children in grades 2 through 6 were tested with a motion picture format, following instruction by their regular classroom teachers. It was concluded that it was feasible to teach selected aspects of the particulate nature of matter to children at these grade levels.

Intermediate grade children's attainment of the concepts "light" and "sound" was studied by Nelson (93). A total of 118 pupils received instruction from teachers who had participated in a workshop in physical science. Each teacher followed his own methods of instruction. Based on the results of a pretest-posttest design, Nelson found a significant gain in the children's understanding of the concepts "light" and "sound." There was also a significant improvement related to the child's grade in school. Children's test scores were significantly related to their intelligence but pupils with high and low socioeconomic background showed approximately the same gain in test scores.

In 1961, Atkin (9) selected certain science concepts considered basic to modern astronomy by professional astronomers. The students involved had IQ's in excess of 105 and were enrolled in grades four, five and six. It was assumed that if brighter children could not grasp the concepts involved, it was unlikely that children of lesser ability would be able to understand them. Following instruction consisting of about 25 sessions each approximately 45 minutes long, Atkin concluded that the children could learn these astronomy concepts even though they did not consider them closely related to their personal and social needs.

A problem-solving approach was used by Weaver and Coleman (154) to assess the relationship between children's mental abilities and their development of meaningful understandings and formation of the concepts of time, change, and variety. A total of 26 first grade children received instruction. It was concluded that average and below-average mental ability first-grade children could develop science concepts when taught by the problem-solving method.

In 1960 King conducted a study (70) including 1,235 children aged six to eleven. He found that there were certain science concepts that children formulated through experience without formal teaching but that concepts such as length, weight, direction, and volume could not be understood solely by experience.

Inbody (59) worked with a group of 50 kindergarten children ranging in chronological age from 64 months to 80 months. After examining the nature of their understanding of the physical phenomenon used, he concluded that there was little doubt that the nature of children's thinking changed with maturity and experience. Also, the type of thinking a child could do at any given time placed limitations on the type of instruction he could possibly utilize.

Smith and Victor (141) designed a series of instructional units consisting of demonstrations and reading materials specifically designed to assist children in understanding generalizations about the concept "light." An instrument designed by the investigators was utilized in assessing the children's level of concept attainment. The 260 pupils in grades four through six appeared to have difficulty with questions which asked for the meaning of a word, which required the pupils to identify the shape of an object, which asked for an application of the concept, and which required knowing the meaning of at least two objects or definitions and applying them in a complex situation.

Palmer (101) randomly selected a group of 36 students from three randomly selected classes of BSCS Biology (Green). Students were further divided into three ability levels. The problem was to determine the role of the laboratory in concept formation and the total instructional program. Data were collected through a series of structured interviews related to processes, procedures, and mental activities judged to be primarily acquired through laboratory situations. Middle and upper range students acquired more comprehensive concepts than did those in the lower group. Auditory experiences and thought experiences appeared to have more impact on concept formation than did visual and direct manipulative experiences. While the laboratory did not contribute directly to the acquisition of factual knowledge needed to formulate concepts, it did, however, contribute significantly to those mental abilities and processes prerequisite to concept formation. Concept formation occurred primarily by interrelating small amounts of factual materials through the ability to think and reason effectively. Conceptualization appeared to be dependent more on the ability to think critically and reason effectively than on any other factor.

Other studies employing a specific instructional sequence to teach science concepts to elementary school children were conducted by Carey (29), Stauss (143), and Helgeson (53). These studies were designed to teach children selected generalizations related to a major science concept or conceptual idea. Carey's study dealt with the particle nature of matter including ideas prerequisite to formulating a concept of ion or ionization. A total of 16 statements served as a focus for 15 instructional lessons presented to groups of average and high ability students in grades two through five. The success of the instructional sequence was measured with a set of multiple choice examinations including questions of knowledge, comprehension, and application. There appeared to be a hierarchy in terms of children's ability to learn the generalizations and concepts. This hierarchy was a function of the grade level and intellectual ability of the pupils and the level of concept mastery desired. Children had sufficient success with several of the theoretical ideas involved, implying that not all science concepts in the elementary school need be of a concrete nature, at least when the criterion for inclusion is whether the children can learn <u>something</u> worthwhile about the concepts.

Helgeson (53) analyzed the concept "force" and selected eight generalizations which gave a measure of students' understanding of the concept. Lessons were prepared for use with children in grades two through six.

Assessment of concept attainment was accomplished with multiple choice examinations that included knowledge, comprehension, and application items. Children at all grade levels met the minimum criterion for success for the first three generalizations and children in grades four through six met the minimum criterion for at least seven of the eight generalizations. At the comprehension level, pupils in all grades met the minimum criterion for the first four generalizations and pupils in grades five and six met the minimum criterion for success for all eight statements related to the concept. At the application level, children in grades four through six met the minimum criterion for success on six or more of the eight statements.

Stauss (143) selected eleven generalizations related to the concept "biological cell" and prepared instructional lessons to teach the generalizations to children in grades two through six. Conclusions were reported on the basis of the children's level of attainment, relative to knowledge, comprehension, and/or application items, for each of the eleven generalizations. Overall Stauss concluded that a pupil's chronological age was not a factor in determining his level of mastery of the concept "cell" at any desired level of understanding. However, the degree of relationship between concept test scores and IQ was greater at the higher grades (four through six) than at the lower grades (two and three), irrespective of the level of mastery. It appeared that certain generalizations related to the concept "cell" were appropriate for inclusion in the lower elementary grades' science curriculum. Decisions concerning which generalizations were to be included was a function of the level of concept mastery desired.

Billeh and Pella (15, 16) report two studies related to children's attainment of various aspects of the concept "biological cell." The 1970 study reports the results of a study with Jordanian children in grades three through six. (The materials were identical to those used with a group of American children.) Students were instructed in eleven aspects of the concept and tested on each facet with questions representing the knowledge, comprehension, and application levels of the Bloom taxonomy. The general trend in attainment, a decreasing one, was from knowledge to comprehension to application. Comparisons of success between Jordanian and American children on the eleven aspects showed some higher, some lower and some the same. The 1972 study grouped the eleven aspects of the concept in terms of the relative degree of association with observable phenomena, labelled as classificational, correlational, and theoretical. Results were examined in terms of mental maturity and ability level. At the classificational level students in grades four, five, and six achieved higher scores on linear and quadratic components. There was no grade level-ability interaction but, within grades, highs did better than lows. Success at the knowledge level was greater than at the comprehension or application levels. For the correlational aspects, students in grade four achieved higher scores than did those in grades three, five, and six. Again high ability students did better than low ability students within grades, and the attainment level decreased from knowledge to comprehension to application. No significant differences for grade were achieved on the theoretical aspects, but again the factor of greater mental maturity was evident. Overall, grade level was a major influencing factor, but it was

not linear. Mental maturity was a contributing factor within grade level. There was a general decrease in success from classificational to theoretical levels and from knowledge to application levels within the aspects of the concept.

Raven (118) gave children in grades three through six a randomly assigned set of eight tasks on speed and acceleration. The problem was to emphasize the development of logical relationships between distance, velocity and time rather than the algorithmic relationship $a = v/t$. Results were in close agreement with Piaget's findings. However, there was indication that there may be some differences in achievement between the tasks that require extensive logical operations among a series of subconcepts and the tasks which require intensive logical operations between a concept and one of its subconcepts. The data suggested that simultaneous and successive motion activities involving the use of intensive operations could be presented to third and fourth grade children. Activities involving successive motion that use extensive logical operations could be used with some fifth and sixth grade children.

Other methodological studies include those conducted by Boles (21) and Agin (1). They used instructional sequences organized around the sociohistorical development of biology and atomic energy to teach selected conceptual ideas about the respective topics to high school students. The results of their studies indicated that students could learn selected concepts when the substance of study was presented in a more social context.

Comments

Most of the studies in this area dealt with the ability of children in the upper elementary grades to learn concepts from the physical science area. Overall the children appear to have had some success in learning the concepts but they seem to be hindered by an inability to generalize. This shows up in the studies where taxonomies of questions have been used. There is a notable decrease in success with the concepts from knowledge, to comprehension, to application. At the upper limit of the elementary school this inadequacy in the ability to learn begins to be overcome.

The area which has received the most emphasis is the particulate nature of matter. Several investigators have pursued work in this area. As would be expected, children in the elementary grades have been most successful. A potential reason for this is illustrated by those studies in which it was demonstrated that it is the upper elementary school child who is beginning to be able to cope with logical operations.

Other findings suggest valuable ideas for future research. Children do better with concepts that they see directly; certain concepts are readily learned from nonschool situations, but others are best developed in school situations; children can and will learn what they do not consider to be high priority items; and, it does not help to do laboratory work and manipulate materials unless the information gatherer has the skill to think and process that information.

The cross-cultural studies and the use of historical ideas to teach concepts are areas which deserve further exploration.

METHODOLOGICAL COMPARISONS

Comparing Instructional Techniques

In these studies science concepts are taught to children by two or more instructional modes. The intent is not to determine the level of concept attainment per se but rather to determine whether one instructional technique was more effective than another in increasing children's level of attainment. One such study was reported by Smith in 1966. He prepared two instructional sequences to teach selected astronomy concepts to sixth grade children. One group received a 40 minute lecture demonstration in a planetarium and the other received a 40 minute lecture demonstration in the classroom. Smith presented both modes of instruction and administered the same objective test to each class receiving instruction. A total of 700 students participated. Those students who had experienced the classroom lecture demonstration achieved significantly higher scores than did those experiencing the planetarium lecture demonstration.

The ability of fifth and sixth grade children to achieve and retain factual material and applications related to electricity and magnetism was studied by Brudzynski (23). Instruction was provided by an inductive method and by a lecture-demonstration method. An attempt was made to create a pupil-centered atmosphere in the inductive classes and a teacher-dominated atmosphere in the lecture demonstration classes. A unit of six lessons was taught by the respective classroom teachers after receiving in-service instruction. Achievement was measured immediately after instruction and six weeks later. Brudzynski concluded that the lecture demonstration instruction had been a slightly superior method to that of the inductive method procedure, especially where girls were involved. Neither method was superior to the other on retention.

Gilman (45) used science concepts as the content base for determining the effect of feedback modes in conjunction with a computer-assisted autoinstructional program. A total of 30 general science concepts were taught. The distinction in feedback treatment groups was a difference in feedback modes--feedback of correct or wrong, feedback of the correct response choice, feedback appropriate to the student's response, and a combination of the feedback modes of the previous groups. Those groups receiving feedback to correct responses scored significantly better than did those groups which were required to discover the correct response.

Marks (82) compared the cognitive preferences of students enrolled in Chemical Bond Approach (CBA) chemistry with those of students enrolled in a traditional high school chemistry school program. The four cognitive preferences were memory or recall of specific facts, practical application, critical questioning of information, and identification of a fundamental principle. Pretest data indicated that there were no significant differences between the CBA group and the control group in the four areas of cognitive preference. However, on the posttest statistically significant results were obtained between the CBA and the control group in three of

the four areas. CBA students exhibited a stronger preference for critical questioning and the fundamental principle options, and the control group showed a stronger preference for the memory of facts option. Both groups had virtually the same preference for the practical applications. Marks discounted the possibility that the students' cognitive preferences were related to their abilities.

Dallas (34) selected ten science concepts and taught them to preservice elementary school teachers utilizing identical procedures but varying the sequential order of presentation in the two different instances. No significant differences were obtained between the experimental groups or between the experimental and the control group. There was also no apparent relationship between the student's application behaviors and various personal characteristics such as mathematical or verbal aptitude, science background, student's performance in college, college background of the student's parents, or the student's level of dogmatism.

Additional methodological studies have been conducted to estimate the comparative effects of various methods of instruction in effecting science concept attainment. These studies span the curriculum from the early childhood years through the college level. Studies at the elementary school level reflect a heavy Piagetian influence while those at the college level are often characterized by Ausubelian learning contentions. In some studies the dependent variable is the attainment of specific concepts while in others the dependent variable is a gross measure of cognitive achievement.

Humphrey (58) employed physical education activities to teach a battery of ten science concepts to slow learning (designated by IQ) fifth graders. The success of the experimental group was found to be significantly greater than that of a group taught through a verbal presentation format on both a posttest and a retention test.

Other studies concerned with method of instruction were conducted by Phillips (105) and Siegel and Raven (136). Phillips sought to investigate the possible existence of a sequential set of conservation concepts leading to conservation of displacement volume as a function of the object doing the displacing and the medium being displaced. Students in grades three, five and seven were confronted with a twelve-task hierarchy either by object or graphic presentation. Analysis by modified Buttman scalogram analysis revealed no method difference, but the results followed the general pattern of the hierarchy with one task out of order. Siegel and Raven assigned a group of fourth grade children to three groups to determine the effect of equipment manipulation on acquisition of the concepts of speed, force and work. Each student in the two treatment groups received nine hours of instruction, three hours per concept over a period of five to six days. All received a guidebook with directions, response spaces, etc. All manipulators had their own equipment. Testing was accomplished by presenting individuals with concrete referents in terms of the positions of pieces of equipment. Both treatment groups achieved scores significantly greater than did the control group, but there was no significant difference between the manipulation group and the demonstration

group. It was concluded that students could focus on the relative interactions visually without the necessity of mathematical expression.

Allen (3), Howe and Butts (55), and George and Dietz (43) have conducted science concept learning studies associated with specific elementary school science curriculums. Howe and Butts (55) compared the performance of groups of fourth and sixth grade students using Science - A Process Approach (S-APA) to groups using a program based on a task analysis of conservation of volume. A Test of Volume Concepts for groups was prepared by adapting Piagetian items on displacement and space volume. A related Learning Hierarchies Test was constructed by identifying subordinate tasks to displacement volume and volume-as-space-occupied. Students using S-APA earned significantly higher scores ($\alpha = .01$) at the fourth grade level. On the Hierarchies Test both fourth and sixth grade children using S-APA earned higher scores than did students in the other program.

Allen (3) found by comparing a group of second grade students using SCIS to a non-SCIS group that the SCIS program did a better job of promoting its own cognitive goals. George and Dietz (43) administered a locally developed test of problem solving skills to a group of low income urban first graders who had completed a semester of work with SCIS. Scores on tests of attainment were found to exceed those of the norming group in three of the four classrooms tested.

Voelker (152) compared two methods of teaching the concepts of physical and chemical change to elementary school children. He found that the children who were expected to generalize the concepts were no less successful than those children who were specifically guided in concept acquisition by the teacher. Children in grade six only met the established criteria for mastery. Of note is the fact that the children in the lower grades were on a par with the older children when they had an opportunity to demonstrate their understandings rather than to express them verbally.

Several methodological studies have also been conducted with high school students. Bass and Montague (14) reported a study with 133 ninth grade students where they tried out a science instructional sequence in relationship to the development of children's ideas. A see-saw type balance and a cart on an inclined plane were used to measure the development of the concept of equilibrium. Piagetian stages for the two problems were converted to instructional objectives and the students were provided with three one-hour self-instructional lessons. Comparison of pre-test and post-test results showed a tentative validation of the hierarchy of objectives for the balance but not for the inclined plane; instruction helped the students progress through stages.

Jerkins and Novak (63) used three types of supplementary materials in conjunction with the Midwest Program on Airborne Television Instruction to measure seventh and eighth grade students' information acquisition and concept development. Three types of supplementary materials (participant, redundant, new) were prepared based on Barrow's theory of effectiveness of audio-visual communication participation. Measurement of knowledge

acquisition and understanding was based on Novak's concept attainment model and the Taxonomy of Educational Objectives. Students who had used participation materials scored higher than those using non-participation (.05) in both grades. Students in grade eight did better than those in grade seven. The largest gains were at the 1.1 level of the knowledge portion of the taxonomy. Gains in understanding were only spotty.

In a comparison of independent study, small-group discussion and large-group presentation, Hug (5) found that high school students preferred independent study, but there were no significant differences on the cognitive gains for the methods of instruction.

Computer simulations were used by Boblick (17, 18) to assess discovery of conservation of momentum and to teach the gas laws. In the conservation of momentum study a computer simulation program was prepared that could simulate a "perfectly elastic collision." Data could be collected and guide sheets were provided. High school physics students were randomly assigned to participate in this program or to use the PSSC method of learning the concepts. A pre-test was utilized to eliminate possessors of the concept; an instruction period of 55 minutes was presented to the remaining students. Post-test results showed significant gains by both groups (PSSC, .05; Simulation, .001). Gains by the computer group exceeded those of the PSSC group (.001). In the second study three gas law relationships were taught to students by a simulation or through problem drills. Both groups made significant gains, but the computer groups achieved significantly higher scores than the problem group (.01).

Set induction was used by Schuck (132) in a study with BSCS biology. Half of a group of preservice teachers was trained in set induction. All teachers then taught units on respiration and circulation. Students taught by teachers trained in set induction achieved significantly higher scores than did the others on both achievement and retention (.01), and pupils of set induction teachers judged their teachers more effective (.01).

Weisberg (155) developed a set of visual advance organizers for use in teaching the theory of continental drift to eighth grade students. The organizers consisted of a verbal description of the ocean floor, a series of profiles of the North Atlantic ocean floor, and a Heezen-Tharp Physiographic Diagram of the North Atlantic ocean floor. Instruction consisted of an 1,100 word learning task. Both treatment and prior knowledge were found to have an effect on the results. The expository organizer did not function, but the visual organizers did. The graph was "almost as good" as the map.

The effect of pacing and choice of materials in auto-tutorial instruction was studied by Kuhn (72). Elementary education students, mostly female, in a general biology course were given flexible study time with selected laboratory materials. The open lab on the plant kingdom allowed from two to four hours of study time. Both knowledge acquisition and retention were measured. A test of analytic ability was also given. The time factor was significant at .01 and the analytic ability factor was

significant at .001. Increased study time enhanced retention for all the "analytical" groups.

Comments

Methodological comparison studies also focused primarily on the elementary school program. However, in comparison to the studies reported in earlier sections, there is an increased emphasis on high school and college students. Studies with elementary school children continue to make heavy use of Piagetian ideas while those with college students draw heavily from Ausubelian learning postulations.

Results of the studies seem to indicate that students are most successful when they are confronted with rather traditional instructional approaches. For example, several studies report that classroom demonstration approaches are superior to more inductive and discovery oriented approaches. At the same time, however, there is reason to suspect that these are short term studies with children who have no experience in using the less didactic approaches and that the tests of "concept attainment" are designed to favor information acquisition. The measurement of concept learning is not often an independent factor from the methodology. Methods determine the nature of the assessment device rather than method and device being independent.

More recent comparison studies depend heavily on one of the newer non-text oriented curricula. Results of these studies indicate that programs designed to foster the learning of selected process and product concepts and higher cognitive learnings such as problem-solving are more effective than those that are not designed for this purpose.

Two of the more interesting findings in this section relate to preparing teachers to use specific methods to teach concepts and to the use of computer simulations to teach concepts where the use of physical models may distort the theoretical postulation. The results of the simulation studies demonstrate clearly the potential shortcomings of the use of models and certain kinds of demonstration activities unless the students are extremely capable of thinking in terms of abstractions and can readily relate the mental model and its physical representation. The set induction work leads one to suspect that the lack of conclusive results from comparison studies is due to serious inadequacy in design. The interactions between students' readiness to profit from a method, teachers' ability to use an approach, and the appropriateness of the methods to the nature of the concept and the expected learnings are extremely complex. They have not been given careful analysis.

A significant outcome is that the cognitive and analytical abilities of the learners entering any one of several instructional environments is a far more critical factor than the method itself until the concept, method, learner network has been more carefully designed.

CURRICULAR CONTENT

Studies of this nature are specifically designed to identify and/or select concepts, principles, or other conceptual ideas which can serve as the base for structuring the science curriculum. The usual approaches are to formulate a questionnaire and send it to samples of professionals and consumers including teachers, curriculum coordinators, administrators, and professional scientists; analyze existing materials for teaching science; or employ some combination of these. A wide variety of questions are asked. For example, respondents may be asked to judge whether particular concepts or conceptual ideas should be included as curriculum goals for a designated level of the science curriculum, whether these ideas should be taught at a particular grade level, or to what extent the specific substance should be emphasized. Many lists are limited to those entries derived by the investigator. In other instances the respondents are asked to make judgments about the entries presented by the investigator and are asked to make suggestions for additions to the list.

One such study was conducted by Leonelli (77). He asked several questions, two of which were, "What physical science principles should be included in the K-6 curriculum?" and, "In what grade or grades might these principles be introduced?" Most principles were judged appropriate over a range of two to three grades. Although the results were wide and varied, the bulk of the respondents felt that the primary reason for including physical science principles in an elementary school science curriculum was to encourage the children to be more interested in their environment and to better interpret it.

Thelen (146) and McCombs (85) conducted surveys of existing science content for inclusion in the curriculum. Thelen surveyed textbooks, laboratory manuals, curriculum guides, and methods and materials books to compile a list of chemistry facts and concepts which might be important to understanding high school biology. Judges rated each fact or concept as very important, fairly important, or of little or no importance to the understanding of introductory high school biology. One hundred forty-nine facts and concepts of chemistry were designated as being very important for understanding introductory high school biology. Over 300 other facts or concepts were rated as being of lesser importance. McCombs surveyed science textbooks, K-12. Her survey led to the identification of three concepts for each major science area included in the high school curriculum. From this list, 12 biological and 17 physical science concepts were selected for use in the primary grades. Laboratory experiences were then designed to provide K-3 pupils with guidance to the understanding of the concepts. Major conclusions were: (1) development of basic science concepts should be a primary objective of elementary school science, (2) psychological characteristics of the child should be more carefully considered in planning the science program, (3) children's ability to recognize casual relationships should be developed through appropriate science experiences, (4) generalizations and concepts should be developed through problem solving and subsequently applied inductively.

More recent studies of this nature have been conducted by Janke (62), Thompson (149), and Roth, et. al. (125). Their objective was to obtain the judgment of professionals regarding the long-range goals of earth science, biological science, and environmental management curriculum respectively. Janke and Thompson's studies focused on the K-12 science curriculum while Roth's study focused on the K-16 curriculum.

Janke and Thompson conducted personal interviews with professionals in the designated substantive areas on the University of Wisconsin-Madison campus to compile an initial list of conceptual ideas. The procedure was designed to elicit statements pertinent to the basic substance of the general area as well as produce statements pertinent to the many sub-area specialities. The resulting concensus list was sent to samples of scholars in the disciplines who rated the statements from unsatisfactory to highly desirable for inclusion in the K-12 curriculum. Janke's study resulted in a list of 52 statements rated from satisfactory to essential for inclusion in the earth science curriculum. An analysis of a sample of textual materials for use in earth science programs revealed that a majority of these conceptual ideas were included. The ten ideas related to "environment" were least apt to be included in the materials.

Thompson's work produced a list of 114 conceptual statements. Similar ratings were given to the statements by university biologists, science educators, and high school biology teachers.

Roth, et. al. used the same basic procedure except that they developed from a survey of pertinent literature an initial list of statements for reaction by the Wisconsin campus panel. This study resulted in a list of 111 conceptual ideas acceptable to 90 percent or more of the respondents.

Comments

These studies produced lists of conceptual ideas that can be analyzed and broken down in lesser concepts and principles for inclusion in the science curriculum at various levels. At a given point in time they can be used as a criterion for determining the concept currency of existing or developing science curricula. They indicate what conceptual content withstands the test of time as well as identify ideas at the forefront of developing knowledge.

To be of any long-term value, however, these studies will need to be replicated and expanded on a continuing basis. Their value on a one-shot basis is nil in comparison to the assessment of status over time. They also need to obtain more input from the consumers of the lists. No matter what the professional scientist thinks is appropriate for inclusion in the curriculum, the local school personnel ultimately determine what is deleted, emphasized, or added.

INSTRUMENT DEVELOPMENT

Many investigators whose studies were reported earlier expended substantial effort in the development and refinement of valid and reliable instruments as a necessary part of their studies designed to measuring concept attainment outcomes. But others have prepared instructional sequences for the express purpose of providing input prerequisite to preparing and refining instruments. The major intent has been to improve the quality of the instrumentation rather than assessing the level of concept attainment prior to or following instruction.

Several researchers have recognized the advantages of using interview techniques and other non-paper and pencil techniques for measuring concept attainment, especially those who have conducted Piagetian type studies. One particular advantage of the interview technique, supported by Thier's work (147), is that it can be used to overcome language difficulties in measuring children's concept attainment. He found the approach particularly useful in his work with first grade children.

Other investigators, including Haney (48) and Boener (20), have addressed themselves to the difficulties encountered in measuring young children's concept attainment. A major concern in both instances was children's lack of verbal skills. Haney discussed some of the problems found during the development of a 40-item nonverbal concept test on animals. Some of these problems relate to color and size and raise questions about the appropriateness of such tests. Boener found that line drawings can be used to overcome certain difficulties encountered in trying to approximate characteristics of real objects and living things.

Doran (38) and McIntyre (26) both report work in the preparation of motion picture tests for measuring elementary school children's concept attainment with respect to the particle nature of matter. McIntyre describes the advantages of this type of instrument for use with groups, which included overcoming the inability of children to verbalize concept understanding and lessening the time needed to administer tests to individuals. Procedures used in construction of the test and the establishment of its psychometric characteristics are described. Doran described how the distractor choices in the various items can be used to identify students' learning difficulties. He suggested the potential of reorganizing tests items to form new tests and subtests for use in assessing learning difficulties.

Atwood (12) described the development of a cognitive preference examination focusing on general science and social science content. The test was designed to estimate students' preference for activities involving memory, application of information, or the questioning or challenging of information. Preliminary work indicates that the measure is stable.

Comments

These studies point up the desirability of and the necessity for giving more careful thought to the nature and construction of assessment devices. Throughout all the previous sections there is evidence of the evaluation portion of the studies being a limiting factor in the outcomes of the study and its potential for generalizing the results. Much more emphasis must be placed on the development of instrumentation which gives consideration to the desired outcomes of the research in conjunction with the communicative abilities of those students involved. This interaction is a very complex one and has not received nearly enough care in the bulk of the reported studies.

REVIEWS AND MODELS

The articles cited in this section include literature reviews, theoretical postulations about the nature of concept learning, and studies expressly designed to develop models for assessing concept attainment.

Novak, Ring, and Tamir (94) conducted a survey of research literature related to Ausubel's theory of learning. The analysis was undertaken in an attempt to formulate an underlying framework for guiding science education research. There are many implications for those engaged in research on science concept learning. Of particular import is the obvious concern for how children learn. They describe Ausubel's theory of learning and then discuss 156 studies related to it. Conclusions were formed for three groups of studies: the effect of structured teaching on learning; group vs. individualized instruction; effects of prior learning. A major conclusion that is consistent with the conclusions of this paper is that many studies have no basis in learning theory. And hypotheses are tested that are almost irrelevant to how students learn.

Literature on discovery learning also has implications for those engaged in research on science concept learning. Kaufman (68) examined discovery learning as a concept, a method for teaching concepts, in terms of where the learner gets his input and how he processes that input; i.e., what is his ability to synthesize? He considered principles of learning theory pertinent to learning readiness, meaningfulness of material, activity and passivity, motivation, and transfer of training. He places the work of Hendrix, Suchman, Bruner, Karplus, Gagne, and Ausubel on a continuum from discovery to expository learning. Careful and repeated analysis of this work and the previous paper should give some meaningful insights into conducting research on the learning of science concepts.

Raven (115) also asked researchers to give more thought to the nature of children in organizing their studies. Why should a child be expected to learn in a few days or weeks what it took mankind hundreds of years to develop? He recommended that we study the historical development of concepts and knowledge in order to better understand children's learning

problems. For example, can printed materials or lesson summaries impart the learnings of years to a child? If the child does not comprehend the process of information organization, he will experience difficulty in formulating and generating knowledge. Further, too many lessons deal with knowledge as an absolute rather than something with varying degrees of credibility. If children are to be expected to formulate concepts, then they need to understand how logical relationships are developed and applied.

Johnson, Curran, and Cox (65) posed a model for assessing the knowledge of science concepts, based on two types of psychological relations--association and similarity. These relations were considered estimates of learned relations. Six relational concepts--power, work, force, acceleration, velocity, and momentum--and three operationally defined concepts--mass, distance, and time--were used to develop a structure of interrelatedness. Forty-nine male college physics majors were given a free-association test, a constrained-association test, and a similarity-rating test. The association-to-stimulus-words results generally followed the postulated relations among the concepts, and the results on the constrained-association tests followed the postulated pattern. Acceleration was an exception. Similar results corresponded well with the model. It was suggested that these two approaches may be different ways of measuring the same thing.

Comments

Inclusion of these reviews was done purposely because of the obvious deficiencies in the conceptual framework of the reported studies on concept learning in science. One difficulty is that many researchers have forgotten that their work is to enhance the learning of science, not just to use science content to generate learning theory. We would not complain, however, if we could generate some learning theory about the learning of concepts of particular characteristics.

These reviews serve to support the contention to be expanded in the summary of this paper that the research on science concept learning suffers badly from the lack of models for conducting the research. One weakness is the dependence on a particular learning theory rather than seeking the significance of that theory in reference to an aspect or aspects of the cognitive domain of science. There is also not enough emphasis on looking at the interactions of the various theories. Could it be that they talk about the same things but enter at different points of the puzzle?

SUMMARY

On the Positive Side

At first glance, there is a limited amount that can be said about the quantity and quality of research on science concept learning. On the other hand there are indications that fruitful ideas are germinating. If these positive starts are nurtured, the infant state of research on science concept learning may soon reach maturity. Areas showing promise deal with the nature of science, association with learning theory, methodology, approaches to evaluation, and potential for future research.

A research base to use in estimating the potential placement of concepts in the science curriculum is beginning to accumulate. The results of the studies do not give us prescriptions to be religiously adhered to but do provide clues to where we might expect some success in assisting children to learn selected concepts. This work has been enhanced by the utilization of various taxonomies of questions in assessing the attainment of specific concepts and their relationships. The results of many studies verify that developmental patterns exist in children's acquisition of science concepts -- acquisition of factual knowledge to the formation and application of abstract models, for example.

One of the more positive outcomes of this analysis has been the unveiling of clusters of studies devoted to students' understanding of key science concepts. Investigators at several institutions have continued to research student ability to formulate and apply aspects of the particulate nature of matter. In addition, the intensive work done on relational concepts such as acceleration and speed demonstrates a recognition of the need to maintain a sustained attack on a select and basic set of foundational concepts.

Another positive outcome of this analysis was the finding that so much emphasis was placed on physical science concepts. These concepts, heavily relational and theoretical, need to be carefully researched before they are included in the elementary school science curriculum. This is due in large part to their abstract nature and to their dependence on the learner's ability to deal in logical and mathematical operations.

In the conditions of learning area there is continuous and overwhelming support for experience as a key factor in children's abilities to formulate and to continue to refine their understandings of science concepts. Other factors such as I.Q., age, etc. seem to be influential only after a sufficient amount of quality experience has been made available to the learner.

Emphasis on subsuming concepts, process concepts, and other prerequisite skills has increased in recent years. The recognition that the interactions between product concepts and process concepts may be more critical in determining the ability to form either kind of concept than

any other traditionally researched factor such as age or mental ability is particularly heartening. The application of task analysis and Piagetian developmental psychology to problems associated with children's learning of science concepts has also been most beneficial. It is of note that earlier Piagetian inclusions attempted to prove or disprove his ideas. Of late, however, there is evidence that ways are being sought by which these ideas may assist in understanding learning problems associated with the attainment of science concepts. This appears to have come about because of the recognition that developmental psychology contributes to an understanding of the nature of learning rather than assigning cause to learning.

There is little to be said about the methodological studies. However, there are some investigators who recognize that method A cannot be compared to method B until the treatments are in fact different and others who recognize that randomizing the samples out of a mixed population may in fact generate no significant differences. Credit must be given to those who show a concern for the results of children's learning derived from encounters with methods and materials designed to teach specific concepts to children with selected characteristics. These studies produce some general estimates of trends in children's attainment of certain concepts. The use of models to help clarify ideas which can only be developed from secondary evidence or data derived from the employment of measurement devices should be recognized as a developing and much needed research area.

Evaluation of the attainment of science concepts shows some growth in sophistication of approach. The frequent use of the Bloom taxonomy to obtain more consistency in measuring concept attainment will aid in the ability to generalize results. And the recognition of the necessity for multiple measures of concept attainment--film, etc. to de-emphasize the dependence on the ability to read and speak fluently should upgrade future research endeavors.

There is also an indication that some researchers are striving to develop models to focus their efforts. Those who do apparently comprehend the nature of the complex interactions between the structure of science, how children learn, and the development and employment of curriculum and instructional materials.

On the Negative Side

It is always easier to be a critic than to produce even tentative solutions for a perceived dilemma. Possibly this comes from the frustration of seeing that there is so much to do and not enough time to do it. Or, it could be that this analysis has demonstrated that so much time and effort has been devoted to research on science concept learning without any appreciable advances. Some perceived deficiencies producing the diffuse activity will be considered in respect to the structure of science, learning theory, methods of instruction, evaluation or assessment, and general comments.

An inordinate amount of research still seems to be based on the notion that it is necessary to determine how early in the curriculum certain concepts can be inserted. Unfortunately, concern for introduction takes precedence over optimizing learning. Some of this thrust has merit. With the amount of exposure students get today, they are probably as advanced in their knowledge of certain science concepts as were the early professionals. Studies which make an appraisal of what general advances in knowledge have been made by children of selected ages, experiences, and characteristics will be helpful, but this approach takes precedence over "What should children learn" and "How do children learn." Too much time is devoted to "forcing" concepts rather than pursuing an understanding of their development and refinement from the standpoint of the learner. The fact that this occurs suggests that there may be a lack of a credible rationale for conducting research on science concept learning.

Research on science concept learning appears to suffer from the absence of a taxonomy of science concepts. There is literature support, in learning and in science education, that concepts have properties or characteristics. Concepts can also be related to form principles, generalizations, higher order concepts and other more sophisticated conceptual ideas. Yet no one has adequately developed these classes of concepts and their properties to a degree that forms a credible model for facilitating research. Not only are the classes and the characteristics missing, but there is not even an accumulation of groups of concepts, for example a group with common origins in phenomena, that could form an initial set for developing a taxonomy. We have conceptual schemes and generalizations but until these are organized into manageable structures, the research pieces could just as well have come from different puzzles.

Preliminaries to data gathering are missing. In addition to the absence of taxonomies or other models, the individual studies do not demonstrate sufficient concern for concept analysis. Thus, when the results are in, we have a gross measure of achievement rather than useful information which sheds light of the intricacies of learning concepts. For example, when the study is completed do we know whether the students had difficulty with the attributes or the examples of the concepts, or do we know only that they did not fare too well on the final examination? The bases for diagnosis are absent. Some studies concerned with grade placement or the relationship of concept attainment to factors such as learner maturity are useful in their own right but are too expensive to conduct until they help establish the credibility of a model for science concept learning or lead to the postulation of a model.

Application of learning theory to the study of science concept learning is also short of the mark. For one thing, too many investigators accept one of the many theories as the panacea of all concept learning. More study should be devoted to examination of the similarities and differences in the different learning approaches and how they singly or in combination contribute to clarification of the complex interactions between the structure of the discipline, the nature of the learner, and the nature

of the learning environment. There are so many possible combinations that it is practically inconceivable that any one learning theory is the answer to all questions. It would also enhance the research if more of the studies indicated were in fact testing the application of a theory to a specific science concept learning situation and, if so, which one.

A variety of theories is not being studied in reference to a taxonomy of science concepts, different learning environments, or in reference to other pertinent variables. Various learning theories must be examined in the context of the expected outcomes of science concept learning. At present the context is missing and theories are not being considered as alternatives. The present approach belies the existence of individual differences.

There is also some confusion about the application of learning theories to the development and evaluation of total science curricula. Many studies are associated with these programs and related materials but have these programs purportedly based on a particular learning theory been tested in terms of models of learning or the learning of specific concepts? For example have the instructional materials, when used as the developers suggest, contributed to an improved understanding of how children learn science concepts? More emphasis needs to be placed on determining what the goals of science concept learning are and then on research materials based on one or more learning theories to see whether they do contribute to advancing knowledge of how children learn science concepts.

The previous discussion leads to one of the more disturbing results of the analysis. Many studies could just as well have been done by a child development specialist or a learning psychology specialist. Science is being used as a vehicle for doing learning studies rather than examing the contribution of learning theory to the learning of science concepts and the advancement of the goals of science education. Reports of the studies do not clarify positions on this issue and statements of the problems do not reflect a science education emphasis. Admittedly there is some dissatisfaction with structure of the discipline as the driving force behind development of science curriculum. But the structure of science must be carefully analyzed before either learning theory research or science education research can be conducted. Some researchers appear confused about the focus of their work.

Examination of the methodological studies indicates that many lessons, and their main strands, are based solely on the personal judgements of the investigators. The probability that another person, given the same task, would produce lessons of the same general nature is slight, no matter how well the substantive area was known. This is in itself a deficiency, but also the lessons themselves are not described in a form such that they could be reconstructed or used by another investigator to replicate the work or extend it in a new environment. If this is continued we would be better off using commercially prepared lessons in kits or programs because we would be able to control variables. This group of studies is one of the weaker groups within the entire scope of science concept learning

studies for this very reason. Further, plans for the lessons are not derived from a model designed to test the application of learning theory to a dimension of science concept learning derived from an analysis of the structure of the discipline.

Evaluation problems in the science concept learning studies originate from the lack of agreement between the various "testings" and the goals of science education. We would all agree that we desire that the learner attain a high degree of scientific literacy. To the researcher of science concept learning, this includes the conceptual schemes, the key concepts, the generalizations and the other broadly conceived statements of desired outcomes of science instruction but, until these are better defined, we are hampered by not knowing what we are to measure. Constructing a set of achievement tests to accompany a particular science curriculum or program is not the answer. The fact that there are no consistently used instruments across studies focused on an area clearly reveals the lack of credibility that can be placed on the results of a single study or a collection of related studies. Until more emphasis is placed on developing instruments that measure some aspect of science education taken from a well defined framework for concept learning we are wasting time, money, and energy. Use of a taxonomy such as Bloom's is a step in the right direction but such tools have restricted use until we have agreement on what we desire "knowledge of" or what we want students to be able to "evaluate" or "synthesize." In short, we lack standards of measurement. Those instruments that are used are too local in conceptualization and too often have low quality or unreported psychometric characteristics.

There is also an overdependence on the paper and pencil instrument for measuring concept attainment. Even in those instances where films have been used or interviews constructed, the lack of multi-method approaches in measuring concept attainment does not provide an adequate indication of the unique kinds of information obtained by employing a particular measurement device. Many studies would benefit substantially from the use of multi-mode measures.

Overall the measurement process in science concept learning studies also suffers from the lack of development of models specifying what we expect from instruction and curriculum development concerned with the development of science concepts. But models for measuring concept attainment cannot be posed until we have models for what we expect to measure.

There are other comments to make about the state of the art of research on science concept learning. These will not be elaborated here because each could be a treatise in itself. However, each must be taken into account by any concept attainment researcher concerned with generating or verifying theory. If not, his work will be only an assessment of the achievement of a local group in a local situation with local materials; a poor base for generalizing.

1. A notable deficiency of the research surveyed is the absence of rationale. Certainly we want children to learn science concepts and relationships between them, but this is not adequate justification for much of the present activity under the aegis of research. We need an improved conceptualization of the domain of science education and the cognitive knowledge subset of that domain. Once this is eatablished, we need a plan for carrying on learning studies contributing to improved procedure for developing curriculum and organizing for instruction. The lack of rationale (conceptualization) for studies results in outcomes which might have been as easily obtained by extrapolation from general psychology of learning and/or asking an experienced teacher for his or her opinion. If science concept learning is no more sophisticated than this, we should stop expending our time and dollars. We must analyze the structure of the discipline and the nature of the learner and engage in more sophisticated study of those interactions which have the highest potential for improving the learning of science concepts. It is the study of this interface which will produce the models for conducting research and generate the unique character[illegible]payoff of the science concept learning study. The exi[illegible]body of research cannot stand on these merits.

2. There is an overemphasis on comparing curricula rather than on generating knowledge about the nature of science concept learning for use in the development of curricula. Utilization of an existing curriculum can be used to provide instruction for development-oriented research, but the criterion measure for its contribution to the advancement of knowledge should be whether it is being used to test a model of science concept learning in the framework of a well developed model of the goals of science instruction. Otherwise, the studies are only more elaborate forms of the localized study which uses local conceptual structure and employs localized, internal criteria for establishing "success." How well the students do on the specific program goals is secondary to how well the program advances the broader concept attainment goal of science education.

3. The amount of research conducted with students in middle schools, junior high schools, and secondary schools is proportionately much less than with elementary school students. And work with the elementary school students is concentrated on students in the upper elementary grades. Also in the elementary school work there are not enough biological and earth science concepts. This seems to ignore the fact that concepts are developmental.

4. As communicated by the reports, one can only conclude that most studies have been done in isolation. The results cannot be generalized because of the lack of an overall conceptual plan and inadequacies in design. There is no total picture to which to relate. Over time little progress has been made in the development of models which could give power to the individual study and the accumulation of data from many studies. This is not necessarily because researchers have not developed a concept of science education which could give rise to the formulation of models. But certainly improvement in the reporting process would better help determine the sophistication of the conceptual framework.

THE FUTURE

At the risk of provoking argument let me make some suggestions. First, put a moratorium on the empirical study unless there is an attempt to generate or test some learning model. The Piagetian type studies give us information about the general development of science concepts, but even this work needs the assistance of a guiding model of the nature of the science concept.

There is no sense in gathering large amounts of data for quantification without having a handle on the problem investigated. It would be disgraceful if a large portion of the studies identified as science concept learning studies were to continue to quantify trivia. There is much room for productive scholarship in this area that is not dependent on the manipulation of numbers. For that matter, without this input the numbers mean little.

The research effort can be advanced by conducting extensive study of the nature of the science concept. For example the classificatory concept, the relational concept, the theoretical concept should be characterized. Then study how children develop these classes of concepts rather than just looking at whether the concepts can be applied as they have been developed over time. Key concepts need to be identified and researched rather than listing general statements or ideas which embody several concepts and the relationships between them.

Once a structure of the science concept has been identified we can begin to study how children learn these concepts and how we might assist them to learn the concepts. In particular this will require a more thorough consideration of the cognitive abilities of the learner. How do the abilities the learner has affect the classes of concepts he can attain and at what level of sophistication? Such questions must be considered in terms of the characteristics of the concept(s) to be learned.

After the interface of the nature of science concepts and theories of learning have been carefully studied, then it is appropriate to consider what types of instructional media have the higher probability of effecting learning. The network is a three dimensional one and each successive step must be taken in order to evolve that viable model for facilitating research.

Instruction must be designed in a way that produces generalizable results. Lessons must be constructed and reported (described) in a way that permits examination and utilization by other researchers interested in the same concepts. And instruction must be based on a model(s) of concept learning which looks at the interaction of the structure of science, the nature of the learner, and devices for effecting learning. Curriculum development can then follow from an improved understanding of the nature and nurture of science concept learning.

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